APPLICATION NOTE

Characterizing Crosstalk with Aggressor On/Off Analysis Using SDAIII-CompleteLinQ

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Summary

Designers of high-speed serial data systems can characterize the level of crosstalk present on signals by using SDAIII-CompleteLinQ features including the Reference Lane, LaneScape Comparison Mode and the Vertical Noise and Crosstalk package to analyze waveforms in both aggressor-on and aggressor-off transmitter configurations. This application note provides information on how to perform this analysis and to understand and compare noise and jitter results.

For more info watch the video:
"Introduction to SDAIII-CompleteLinQ"

Figure 1: Aggressor on/off analysis using SDAIII-CompleteLinQ

Quantifying Noise from Crosstalk: The Measurement Challenge

Noise superimposed on serial data signals due to crosstalk from adjacent lanes has become a significant signal integrity problem. Quantifying the level of crosstalk has not been easy since serial data analysis has, for the most part, focused on timing jitter rather than vertical noise analysis. Additionally, determining crosstalk is a multi-step process. A measurement must be taken on the so-called "victim" lane with a neighboring "aggressor" lane transmitting, and then another measurement taken with the aggressor line quiet. Comparing these two measurements, which are taken sequentially, adds to the complexity.

Teledyne LeCroy's SDAIII-CompleteLinQ analysis package is designed specifically to make multi-scenario measurements like aggressor on-off analysis using proven tools such as eye and jitter analysis, as well as newer tools including the Reference Lane, which holds both the data and setup from an analysis, the Vertical Noise and Crosstalk analysis toolkit, which quantifies the additive noise due to crosstalk or interference, and LaneScape Comparison mode, a display mode that makes it easy to compare the analysis of one or more lanes to the reference lane. Figure 1 shows a typical analysis.

Aggressors, Victims and Aggressor On/Off Analysis

Aggressor on-off analysis consists of performing measurements on a lane whose signal includes noise coupled in from other sources. This lane is typically referred to as the "victim" lane. Neighboring lanes or other external sources of noise are considered as the "aggressor". It is, however, important to keep in mind that the victim lane also will act as an aggressor, and be a source of noise on an aggressor lane.)

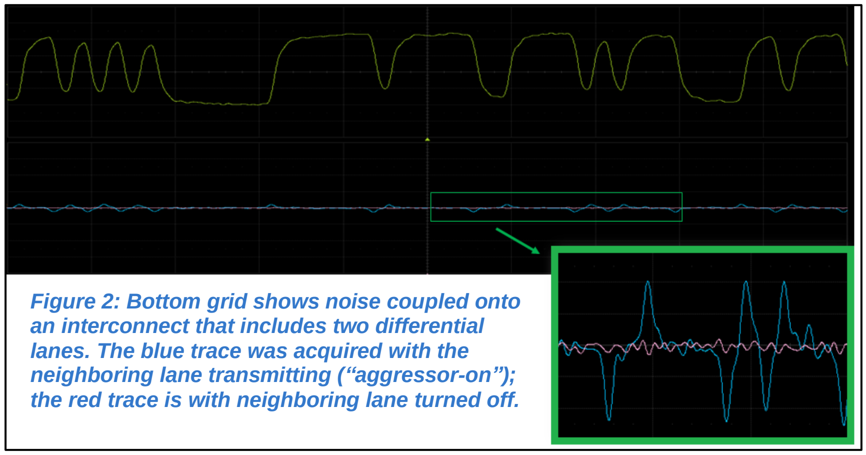


Figure 2: Bottom grid shows noise coupled onto an interconnect that includes two differential lanes. The blue trace was acquired with the neighboring lane transmitting ("aggressor-on"); the red trace is with neighboring lane turned off.

Figure 2 shows traces that illustrate the effect of coupling in an in interconnect with two coupled differential pairs.[1] The waveform on the victim lane (lower grid), taken at the far-end, includes a spike that is caused by the change in state of the signal in the aggressor lane (upper grid). The amplitude of the spike is a function of the risetime of the aggressor signal and the degree of coupling between the lanes. These spikes will be superimposed to any signal that is transmitted on the victim lane, and will have the appearance of vertical noise. This phenomenon can be a cause of eye closure and bit errors. Our analysis in the rest of this application note quantifies this noise as it appears when superimposed on a signal being transmitted on the victim lane.

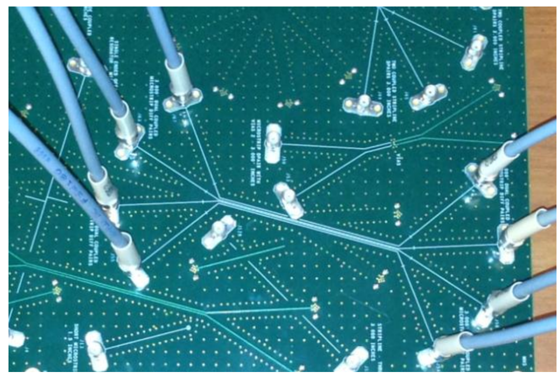


Figure 3 Interconnect with two coupled differential pairs (Wild River Technology CMP-08 board)

What causes this noise, or "crosstalk". Crosstalk is due to coupling that results from the behavior of the electromagnetic field within the device under test. The degree of coupling depends on the topology of the materials in the device. For a full treatment of coupling, aggressors, victims, and crosstalk in all its forms (such as NEXT, or near-end crosstalk, and FEXT, or far-end crosstalk), see Eric Bogatin's book, ***Signal Integrity and Power Integrity, Simplified***. Figure 4 shows how fringe EM fields can couple nets in a circuit.[2] The lower image shows the reality: the EM field in the volume must include field lines that connect different nets.

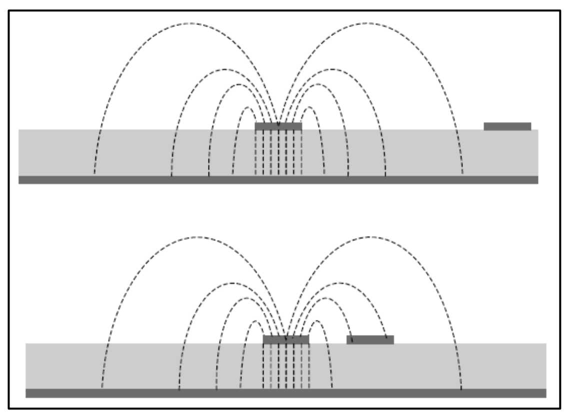


Figure 4: Fringe fields near a signal line. When a second trace is far away, there is little fringe-field coupling and little cross talk. When the second net is in the vicinity of the fringe fields, there can be excessive coupling and cross talk. [2]

[1] Image is a part of the CMP-08 Modeling Platform board from Wild River Technology.
[2] Image and caption for fig 4 are from Eric Bogatin's ***Signal and Power Integrity Simplified***, page 408.

New Tools Used for Crosstalk Analysis in SDAIII-CompleteLinQ

This application note uses the following tools that have been introduced in the SDAIII-CompleteLinQ software package:

LaneScape Comparison Mode

SDAIII-CompleteLinQ includes the ability to view and analyze up to four lanes and the reference lane simultaneously. Users select from one of three LaneScape display modes (single, dual or mosaic) to view 1, 2 or all of these lanes at a time. The LaneScape mode is chosen via the selector control that becomes visible when more than 1 lane is enabled for display. Figure 5 (green highlighted areas) shows the LaneScape selector set to Mosaic mode, and the LaneScapes for lane 1 and the Reference lane.

Reference Lane

Pressing the **Store LaneX to Ref** button after selecting a source lane stores the data and setup from the selected lane into the Reference Lane. After storing to the reference lane, users can modify the set of measurements and views displayed in order to compare eye, jitter and vertical noise results with other enabled lanes. All products in the SDAIII-CompleteLinQ family or products include the Reference Lane feature. Figure 5 shows the analysis for Lane1 and the Reference Lane being displayed side-by-side. The blue highlighted boxes at the bottom highlight the button for storing to the Reference Lane and for enabling it for display.

Vertical Noise and Crosstalk Analysis Measurements and Plots

The algorithms in the Vertical Noise and Crosstalk analysis toolkit quantify the amount of vertical noise present on a waveform due to crosstalk or other interference. The measurements and views included with the Vertical Noise and Crosstalk package are enabled when the oscilloscope is purchased with the Crosstalk, CrossLinQ or CompleteLinQ options[3], all of which enable the XTALK option code. Figure 5 shows the SDA dialog buttons that access the noise and crosstalk analysis capabilities.

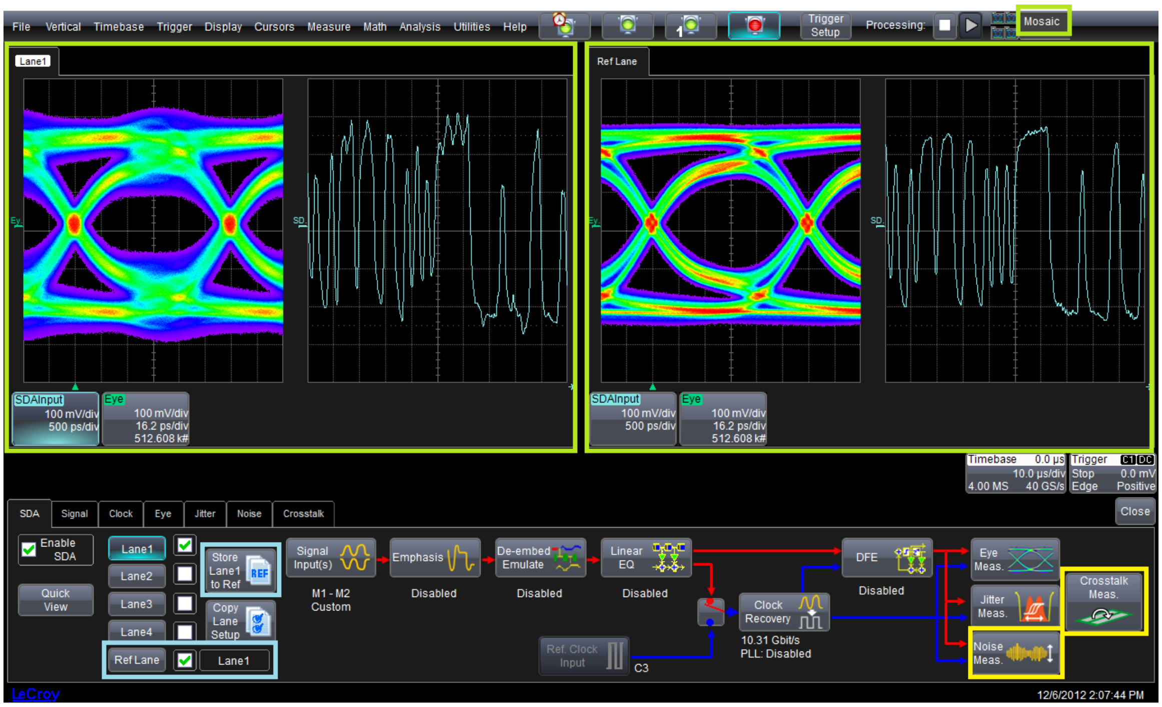


Figure 5: Screenshot showing Mosaic LaneScape view with two lanes enabled. Each lane (Lane1 and Ref Lane) are in their own frame, called a LaneScape. Controls for storing to the Reference lane and for noise analysis are also shown.

[3] See the SDAIII-CompleteLinQ brochure for more information.

Performing Aggressor On/Off Analysis Using SDAIII-CompleteLinQ

The aggressor on/off analysis can be done using either the single-lane or multi-lane versions of SDAIII-CompleteLinQ[4]. In either case, the Reference Lane is used to store the analysis of the victim lane from either the aggressor-on or the aggressor-off scenario. With multi-lane versions of SDAIII-CompleteLinQ, the aggressor lane can be displayed simultaneously along with the victim lane.

Setup

In the example presented here, 10.3125 Gbps signals were used. The victim lane carried a repeating 127 bit pattern (PRBS7) signal, while the aggressor lane (in the aggressor-on scenario) carried a 511 bit pattern (PRBS9). The signals were phase locked, but not phase aligned. The lane-to-lane skew was set at approximately ½ UI. Since the data patterns are different, the noise spike induced on the victim will have a polarity that is uncorrelated to the state of the victim. Thus we expect that the noise will affect both 1 and 0 bits similarly, and be distributed near the center of the eye.

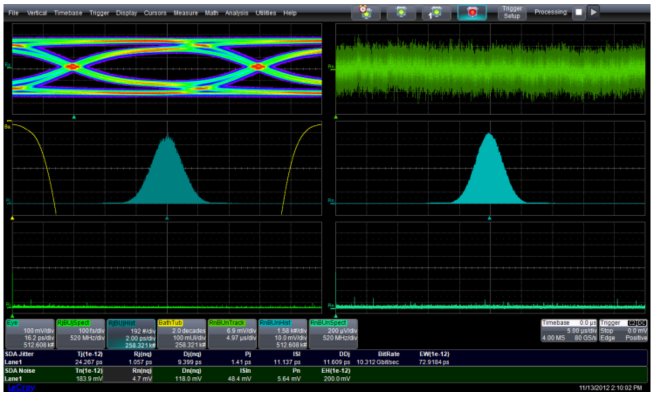


Figure 6: (Output of Step 2.) The analysis of "Lane 1" (lane number not shown) with the aggressor lane turned off is shown. Next step is to store to the Reference Lane.

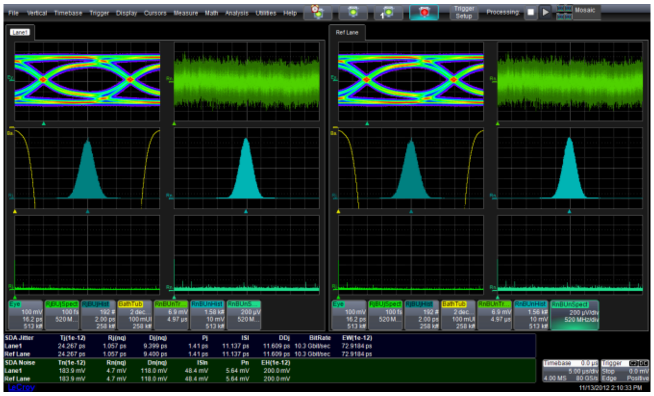


Figure 7: (Output of Step 3.) After storing Lane 1 to the Reference Lane, two LaneScapes with identical data are shown. Next step is to perform the aggressor on analysis.

Figure 8: (Output of Step 6.) After clearing sweeps, turning the aggressor lane on, and single triggering, crosstalk can be seen on Lane 1.

1. Configure the oscilloscope to acquire a set of waveforms from the victim lane with the aggressor lane turned off. Setup the timebase to acquire a waveform that includes > 100,000 unit intervals and >100 iterations of the serial data pattern. This allows the analysis to be completed with a single sweep. (If your signal is not a repetitive pattern, then uncheck "Repeating Pattern" in either the Pattern Analysis dialog for either jitter or noise analysis.)
2. Configure the oscilloscope to perform the serial data analysis. Figure 6 shows an analysis that includes both jitter and vertical analysis for the aggressor-off scenario.
3. Store the analysis to the Reference Lane by selecting Lane 1, and then clicking **Store Lane1 to Ref**. The Lane 1 analysis will be copied to the Reference LaneScape. This is shown in Figure 7.
4. Turn the signal on for the aggressor lane.
5. Press ClearSweeps on the oscilloscope to clear the analysis for Lane 1. The Reference Lane is not affected. *(**Note**: this step isn't necessary if the SDA clock recovery is configured to find the bit rate on every sweep.)*
6. Single-trigger the oscilloscope in order to acquire a set of waveforms for the aggressor-on scenario. Figure 8 shows the resulting screenshot.

[4] A variety of ordering options are available. See the SDAIII-CompleteLinQ brochure for more information.

Vertical Noise Analysis Results

The plots in Figure 6 through Figure 8, along with the noise table give insight into the amount of vertical noise added to the victim lane when the aggressor is transmitting. (see the Appendix A for a description of the process by which noise measurements are determined.) Let's examine these results in more detail.

The SDA Noise Table

SDA Noise	Tn(1e-12)	Rn(nq)	Dn(nq)	ISIn	Pn	EH(1e-12)
Lane1	285.3 mV	6.0 mV	200.8 mV	46.9 mV	107.07 mV	100.8 mV
Ref Lane	183.9 mV	4.7 mV	118.0 mV	48.4 mV	5.64 mV	200.0 mV

Figure 9: SDA noise table, showing the measurement of the noise superimposed on the NRZ data in the victim lane.

The SDA noise table shown in Figure 9 provides summary results of the noise analysis. Tn, Rn and Dn are the result of an analysis that extrapolates the measured noise using dual-Dirac techniques. These parameters characterize the extent of noise out to BER = 10^{-12} (user selectable), in a manner that is similar to SDA timing jitter measurements. (In noise analysis, variations in voltage are analyzed, where in jitter analysis, variations in edge arrival times are analyzed.) We can conclude that the aggressor adds about 101mV of total vertical noise when extrapolating to a BER level of 10^{-12}. The incremental noise is almost completely deterministic[5], (see the Dn result), with the source being the induced voltage spikes. There is a small additive random component due to random variations in the size of the induced spike (see the Rn result).

The ISIn parameter is also only slightly changed. This measurement reports the amount of "noise" that is due to intersymbol interference (ISI). Calling ISIn "noise" is somewhat confusing since the variations in voltage due to ISI are not "noise" at all. Rather, they are due to reflections within the victim channel, and not from coupling to the adjacent lane. (To understand this, consider the eye and signal shown in Reference Lane of figure 1. The "thickness" of the transitions in the eye are a result of the different "trajectories" of the signal due to ISI.)

The noise is also analyzed as being periodic (see the difference in Pn results). The reason for this analysis result is discussed in the section below describing the noise spectrum, which is analyzed to determine the periodic noise result. Virtually all the noise falls into the periodic category, which is a subset of deterministic noise.

Lastly, the eye height is reported in the column EH(1e-12). This is an estimate of the extent of the vertical noise at the *sampling position* or *phase* extrapolated out to a BER of 10^{-12}. With the aggressor lane on, the eye height worsens considerably: from 200mV to 100mV. (We will discuss later on how this compares to the jitter analysis.) The EH parameter better quantifies the vertical eye opening as compared to the traditional "Eye Height" parameter available for display in the "Eye Parameters" dialog. (The traditional "Eye Height" parameter fails to give appropriate results when there is ISI or equalization in the eye, since there is no well-established 1 and 0 level for the algorithm to use in its determination of eye height.)

The measurements in the SDA noise table indicate that there is a difference in the characteristic noise between lane 1 and the reference lane (i.e. between the aggressor-on and aggressor-off scenarios), but they do not give insight into the reason for the difference. The next step is to use the various views of noise to understand the root cause of the noise.

[5] "Deterministic" in this sense means bounded. Random noise and jitter are unbounded; deterministic noise and jitter are bounded.

Noise Analysis Waveforms and Plots

Figure 8 on the previous page shows an analysis in the time, frequency and statistical domains. Let's analyze each.

Figure 10 shows the **RnBUnTrack** waveforms for both scenarios. **RnBUnTrack** shows the noise determined to be superimposed on the victim lane at a user-selected sampling phase. To determine this waveform, the "noiseless" version of the input waveform is determined via pattern analysis, and is subtracted out. The RnBUnTrack waveforms show a distinct difference between the aggressor-on and off scenarios. The RnBUn track can be compared to the data in the aggressor lane (not shown). The RnBUn track spikes align with edges in the aggressor lane.

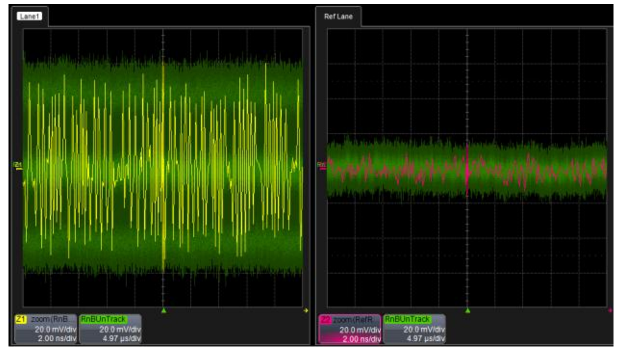


Figure 10: The "track" of the added noise is shown in the RnBUnTrack waveform. Left side shows aggressor on, right side shows aggressor-off.

Figure 11 shows the **RnBUnHist** histograms. These plots show the distribution of the noise found in RnBUnTrack. With the aggressor-on, a tri-gaussian distribution is seen, which is due to the nature of the aggressor. At the noise sampling phase, the induced voltage spike can be either positive (due to a positive transition on the aggressor lane), negative (due to a negative transition on the aggressor lane) or absent (due to no transition on the aggressor lane). The reference lane shows only one gaussian, indicating only random noise on the victim lane when the aggressor lane is off. (**Note**: the horizontal scale for these plots is different by a factor of 10.)

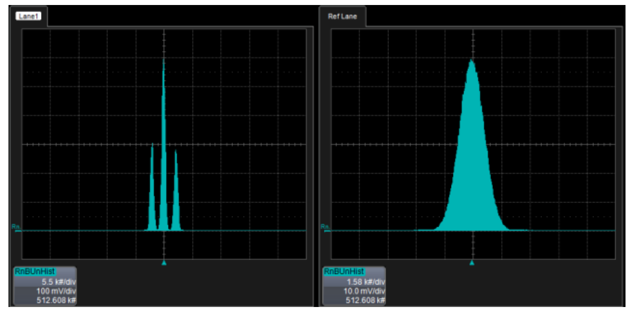


Figure 11: The histogram of the data in the noise track is shown in RnBUnHisto plots. The three states in the left-side plot ("aggressor on") indicate three different noise states due to the aggressor.

Figure 12 shows the **RnBUn spectra**. These plots show the FFT of the RnBUnTrack waveforms. The difference in the RnBUn spectrum between the aggressor on/off scenarios is dramatic. (The jitter spectrum, discussed later on does not show as big of an effect.) The inset in the figure shows a zoom of the spectrum and shows the structure more clearly. We can see equally spaced spectral lines, at Δf = 20.18 MHz. This structure is due to the pattern length of the noise aggressor, which is a 511 bit PRBS11 pattern. At 10.3125Gbps, the 511 bit pattern repeats every 49.55 ns, corresponding to 20.18 MHz. In order to see this structure in the spectrum, the signal must be acquired with a large enough acquisition window (i.e. time per division) to get sufficient frequency resolution in the RnBUn spectrum. (The same requirements apply to the jitter spectrum or any FFT.)

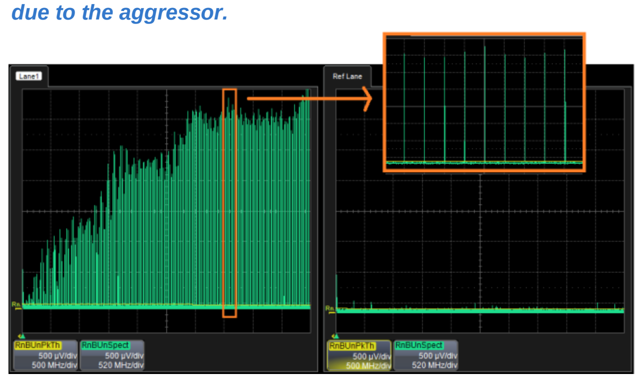


Figure 12: The spectrum of the RnBUnTrack data is shown in the RnBUnSpect traces. The spectrum with aggressor-on shows the expected result from a PRBS11 aggressor.

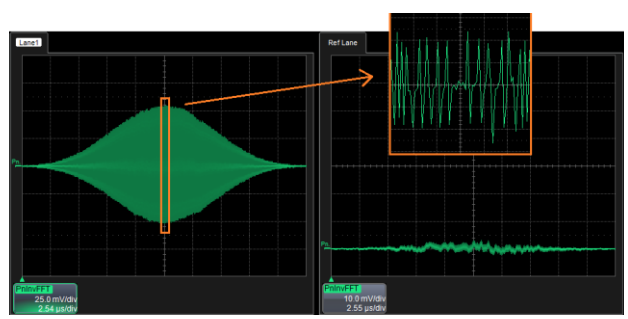


Figure 13: The inverse FFT of the peaks in the RnBUn spectrum provide the shape of the periodic aggressor (inset). The peak-to-peak of the plots give the Pn values.

Finally, Figure 13 shows the inverse FFT of the peaks in **RnBUnSpect.** This plot dramatically shows the impact of the aggressor. The peak-to-peak of the Pn InvFFT plot is associated with Pn. (Note that the vertical scales for Lane 1 and the Reference lane are different.)

Viewing the Crosstalk Eye

The green contour lines that surround the eye diagram on page 1 is the **Crosstalk Eye**. This plot shows the extent of vertical noise as a function of bit error ratio (BER). The Crosstalk eye is a contour map, with each contour estimating the extent of noise at a certain BER value. The power of this view of noise is that it shows the expected extent of the noise via an extrapolation out to BER levels that are not depicted in a traditional eye, which only shows measured data. For example, an eye diagram with 500,000 unit intervals will only show the extent of random noise out to BER = 10^{-5}, approximately[6]. A traditional eye provides valuable information, but it does not show an extrapolation of the measured results.

Simply put, the contours are calculated by (1) performing dual-Dirac fits at 12 points across the eye for each bit in the sequence, (2) convolving the results, and (3) extrapolating the tails of resulting PDFs. This analysis is similar in nature to the measurement of Tn, but performed at 12 points across the eye rather than at the user-defined “Sample Phase”, as is the case for Tn. Contour plots are then formed from the results. The inner set of contours is equivalent to what is called the ISOBer plot (accessible from the Eye Diagram dialog). The outer set of contour lines is useful in order to understand the shape of the noise.

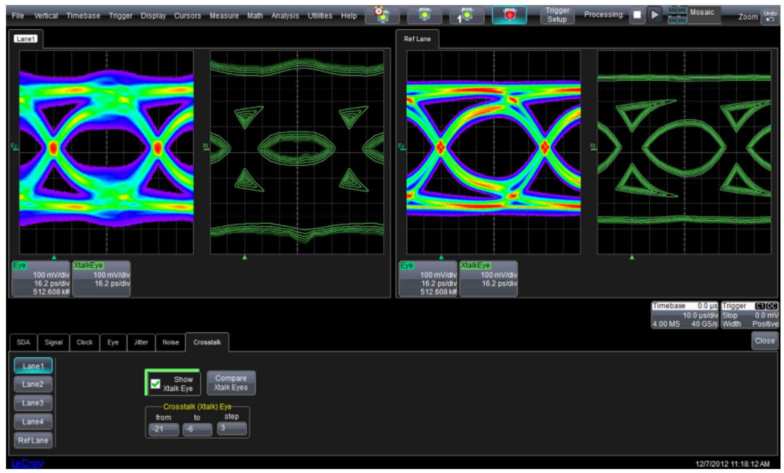


Figure 14: Crosstalk eyes are show alongside the traditional eye diagram Crosstalk eyes are contour maps showing an extrapolation of the vertical noise out to low BER levels. The Crosstalk eye for the aggressor-on scenario is almost complete closed at a BER of 10^{-21}.

The Crosstalk Eyes for our aggressor on/off example are shown in Figure 14. We can see that for the aggressor-on scenario the crosstalk eye contours are close to impinging on the 0V crossing level. The eye diagram does not show such an effect since the eye is constructed from acquired data, and does not extrapolate.

Lastly, we can compare the crosstalk eyes in order to understand any salient differences that cannot be seen by looking at the eyes in the main oscilloscope display. Figure 15 shows the comparison, and shows more clearly how Lane1 has noise that, when extrapolated with the crosstalk eye, intersects the 0V level.

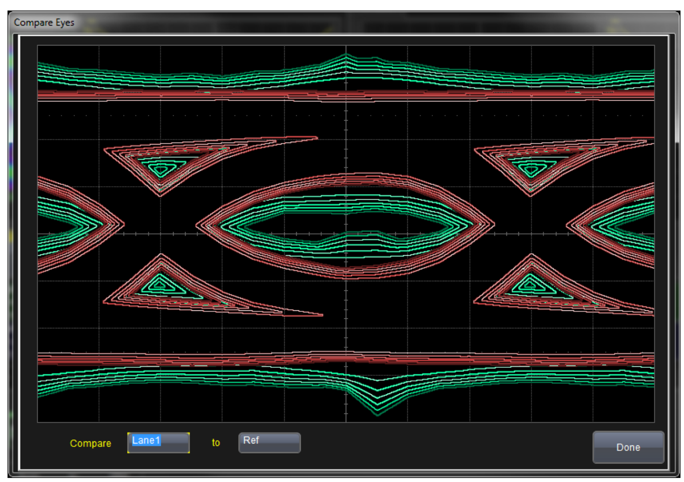


Figure 15: Crosstalk eyes from two lanes can be compared.

[6] The exact value would depend on your choice of confidence interval.

Jitter Analysis Results

Along with the noise analysis, jitter analysis provides insight into the quantity and sources of jitter. In this section, we will discuss the results of the jitter analysis for the aggressor on-off analysis and compare them to the noise results. Jitter is calculated via an analysis of time interval error (TIE) measurements. For more information on the jitter calculation methodology, see the "Understanding SDAIII Jitter Calculation Methods" white paper.[7] It should be noted that vertical noise and horizontal jitter are not independent phenomena. Adding random vertical noise to a signal will show up as added jitter.

The SDA Jitter Table

SDA Jitter	Tj(1e-12)	Rj(nq)	Dj(nq)	Pj	ISI	DDj	BitRate	EW(1e-12)
Lane1	31.661 ps	1.484 ps	10.784 ps	2.77 ps	11.010 ps	11.489 ps	10.3 Gbit/sec	65.6204 ps
Ref Lane	24.267 ps	1.057 ps	9.400 ps	1.41 ps	11.137 ps	11.609 ps	10.3 Gbit/sec	72.9184 ps

Figure 16: SDA Jitter table, showing the jitter on the victim lane for the aggressor-on (Lane1) and aggressor-off (Ref Lane) scenarios. The table shows an increase in jitter when vertical noise is added to the victim due to crosstalk.

The SDA jitter table, shown in provides summary results of the jitter analysis. Tj, Rj and Dj are the result of an analysis that extrapolates the measured noise using dual-Dirac techniques. This allows an understanding of the extent of jitter out to low values of BER. We can conclude that the aggressor adds about 7.4ps of total jitter for a BER level of 10^{-12}. The incremental jitter can be attributed to how the crosstalk (which is a voltage superimposed on the victim lane signal) affects the time that edges traverses a user-selected voltage (the crossing level). Note that the difference in the aggressor on/off scenario results for Tj, Rj and Dj are much smaller than for the noise measurements when considered as a % difference. This is because the crosstalk is dominant at the center of the eye.

The ISI (inter-symbol interference) and DDj (data-dependent jitter) parameters are only slightly changed (as was the case for ISIn in the SDA Noise table). This is expected, since ISI is due to reflections within the victim channel, and not from coupling to the adjacent lane, and DDj is an analysis of jitter synchronous to the victim lane's pattern.

The algorithm that determines Pj returns an increase in Pj of about 1.3ps. (This is discussed further in the section below that describes the jitter spectrum and Pj InvFFT, which is analyzed to determine the periodic jitter result.)

Lastly, the eye width is reported in the column EW(1e-12). This is simply equal to the width of the unit interval (=1/bitrate) less Tj.

In general, summary measurements indicate that there is a difference between lanes or between a lane and the reference, but do not give insight into the reason for the difference. The next step is to use the various views of noise to understand the root cause of the noise.

[7] The paper can be accessed via http://lcry.us/WO9Jox, and is also linked from http://teledynelecroy.com/sdaiii

Jitter Analysis Waveforms and Plots

Figure 17 shows the **TIE Track** and **RjBUjTrack** waveforms. These plots show a "track" of the time interval error measurements before and after the pattern-dependent effects have been removed (TIE Track, top grids, and RjBUj Track, bottom grids, respectively). "RjBUj" stands for "random and bounded-uncorrelated jitter", which is what is left after "stripping out" pattern-dependent jitter. Overlayed on the tracks are zoom waveforms showing a slice of the RjBUj Track waveforms at 5 ns/div. Unlike the RnBUnTrack traces shown in Figure 10, the RjBUj and TIE Track waveforms do not provide much insight into the difference in the aggressor-on and -off jitter results for this particular situation. We can see that the amplitude of the tracks is higher for aggressor-on, but the noise analysis shows a wholly different structure.

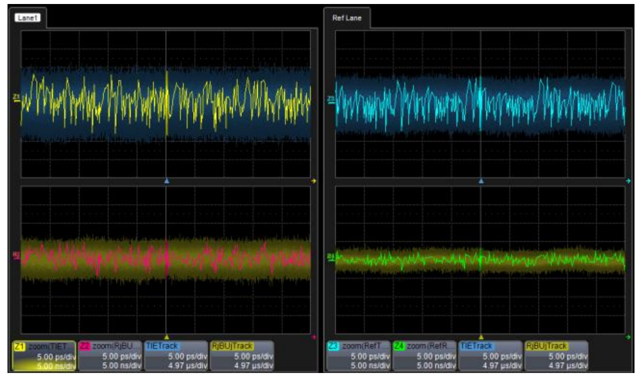


Figure 17: The TIE and RjBUj tracks are shown. Left side shows aggressor on, right side shows aggressor-off. An increase in amplitude can be seen for aggressor-on.

Figure 18 shows the **TIEHist** and **RjBUjHist histograms**. These histograms show the distribution of the data in the TIE and RjBUj tracks. In the aggressor-on scenario, the histograms are wider, but they do not show any dramatic change in features, as opposed to what was seen in the RnBUn histogram (Figure 11). Again, the noise measurement yields more insight into the characteristics of the crosstalk induced on the victim lane.

Figure 18: The histogram of the data in the TIE and RjBUj tracks are shown. While the distribution is wider for aggressor-on scenario, noise analysis shows a more dramatic difference than jitter analysis.

At the bottom are the **RjBUj Spectrum** plots. There is an important lesson to be learned from these plots. We do not see the distinct spectral lines that we see in the RnBUn spectrum (see Figure 12) in the aggressor-on scenario, but we do see a rise in the overall noise floor. This increase is due to the nature of the crosstalk: events that are short in duration will be broadband in frequency. The trouble with this effect is that the de facto industry standard to measure jitter uses spectral techniques to identify Rj, and cannot distinguish the fact that the higher noise floor actually is due to crosstalk. Crosstalk will "masquerade" as higher Rj when using the dual-Dirac Spectral jitter calculation method. See the section below that discusses how the Teledyne LeCroy NQ-Scale jitter calculation method avoids this problem.

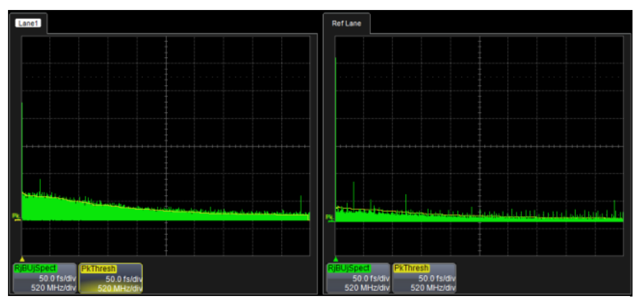


Figure 19: The spectrum of the RjBUjTrack data is shown in the RjBUjSpect traces. The spectrum with aggressor-on shows a higher noise floor, which can lead to incorrect Rj measurements when using spectral jitter decomposition.

Jitter Bathtub Curve Comparison

In Figure 20, we show compare the results for a different multi-scenario analysis. In this comparison, the aggressor lane is turned on in both scenarios, but with a change in the timing between the aggressor and victim lanes. This skew in the timing changes where crosstalk appears. Crosstalk is “lumped” at different positions in the eye for the two scenarios: the reference lane shows the crosstalk centered, while Lane1 shows the crosstalk in time with the edges.

The yellow curve in each LaneScape is the **Bathtub Curve**, which is a easy-to-read visual representation of how Tj varies with BER value. The X-axis is in units of “Unit Intervals”; the Y-axis is BER value. The width of the bathtub curve at a particular BER value shows how much horizontal margin exists at a particular BER. At the BER value selected by the user for the jitter analysis (in this case, 10^{-12}), the distance between the “walls” of the bathtub is simply (1/bitrate) – Tj.

When comparing the curves for the two scenarios, we can see that the bathtub curve is wider in the reference lane at any given value of BER (for example, the vertical cursor shows BER = 10^{-12}). This could be interpreted to mean that the eye is more open in the reference lane. This interpretation, however, only takes jitter into account and does not represent the vertical eye closure. The noise analysis for the reference lane, as seen in the Crosstalk Eye, however clearly leads to a different conclusion: the eye has more closure. The take-away is that a single result, such as a Tj value or Bathtub curve does **not** present the complete picture.

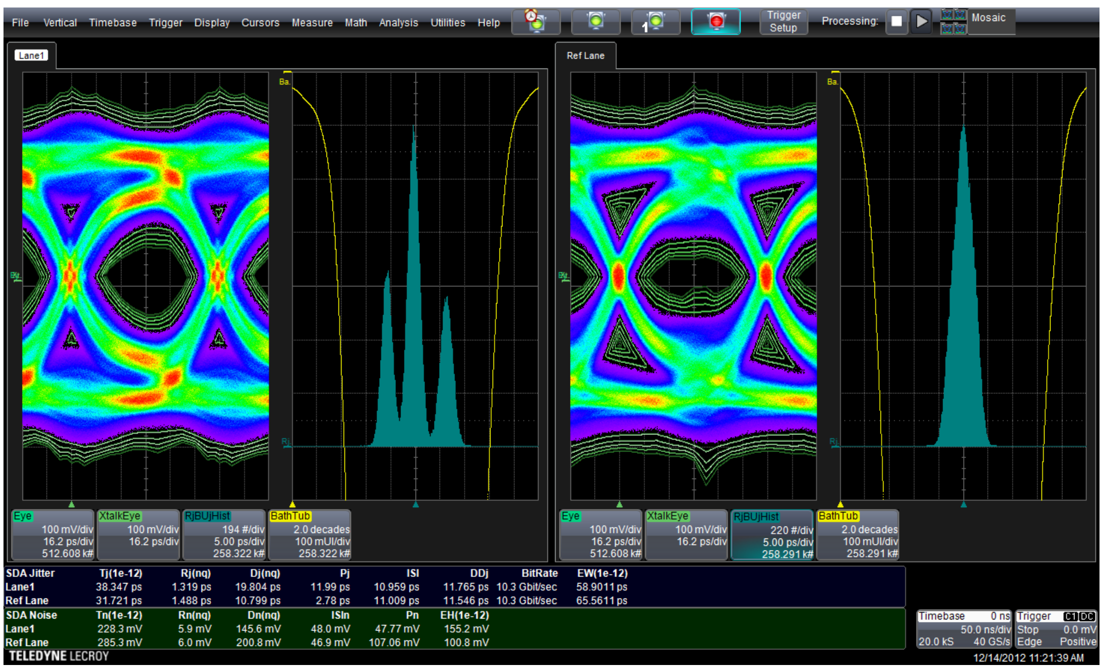


Figure 20: Multi-scenario analysis in which the skew between the aggressor and victim lanes have been varied. The bathtub curve and jitter results imply a wider opening for the reference lane, while the noise analysis indicates that the margin in reference lane is inferior due to crosstalk.

How and Why Crosstalk Can Impair Your Rj Measurement

Crosstalk can have the undesired effect of corrupting your jitter results (on any oscilloscope) when using a spectral method to determine Rj. As described previously and shown in Figure 19, the noise floor of the RjBUj spectrum has risen in the aggressor-on scenario. Unfortunately, industry-adopted spectral techniques that estimate Rj cannot determine that the higher noise floor is due to the crosstalk, and subsequently return an Rj value that is too high. In addition to two versions of the spectral method, SDAIII-CompleteLinQ includes a non-spectral method called **NQ-Scale.** The **NQ-Scale** method does not use the jitter spectrum, and is able to avoid charactering the added jitter as Rj.

Table 1 shows the results obtained for each jitter calculation method for both aggressor-on and off scenarios. The table shows that the spectral method does indeed return Rj values that are overestimated, and that the NQ-Scale method returns a value for Rj that is a better estimate.

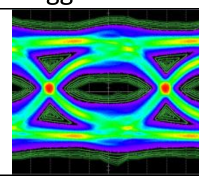
	Rj (NQ)	Rj (Spectral)	Rj (Spectral "Direct")	Eye diagram for Aggressor-on
Aggressor-on	1.484 ps	1.851 ps	1.704 ps	
Aggressor-off	1.057 ps	0.918 ps	0.838 ps	

Table 1: Rj results for different dual-Dirac jitter calculation methods when the crosstalk predominantly is located near the center of the unit interval in the victim lane. The NQ-Scale method returns the most reliable results for Rj in the presence of crosstalk. The spectral methods are "fooled" since the crosstalk masquerades as higher Rj due to the rise in the spectral noise floor.

Consider a different signaling scenario in which the crosstalk is aligned with the edges of the victim lane rather than closer to the center of the eye. In this scenario, the crosstalk will have a much larger impact on the jitter results, since the noise is in time with the edges. Table 2 shows the jitter results for each jitter calculation method. In this scenario, the failure of the spectral method to properly calculate Rj is even more dramatic than in table 1.

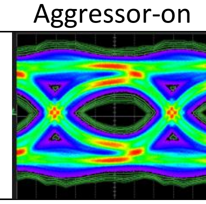
	Rj (NQ)	Rj (Spectral)	Rj (Spectral "Direct")	Eye diagram for Aggressor-on
Aggressor-on	1.314 ps	3.623 ps	3.634 ps	
Aggressor-off	1.057 ps	0.918 ps	0.838 ps	

Table 2: Rj results for different dual-Dirac jitter calculation methods when the crosstalk predominantly is located near the edge times of the victim lane. Like in Table 1, the NQ-Scale method again returns the most reliable results for Rj in the presence of crosstalk. The spectral methods return poor results since there is a dramatic rise in the noise floor of the jitter spectrum.

Changing the Analysis Configuration

Users have a great deal of flexibility in SDAIII-CompleteLinQ. The set of waveforms that are displayed can be modified as desired. Users can select which views of noise or jitter can to display, the number of grids and grid assignments can be changed, the horizontal and vertical scales for all plots can be changed, etc.

The LaneScape Mode architecture synchronizes the grid assignments to facilitate lane-to-lane comparisons, so users only need to change the grid assignment of a trace in one lane, and the oscilloscope application will change the assignments in the other lanes. **Note**: To avoid potential confusion, analysis views for a lane that are enabled from within the SDA dialogs are not permitted to be moved into a LaneScape for a different lane. For example, the Lane1 Eye trace is confined to the grids within the Lane1 LaneScape. However, waveforms that are "outside" of the SDA analysis, including input channels, math functions, zoom traces and memory traces can be moved to any grid in any LaneScape. If you wish to overlay SDA analysis views that are in different LaneScapes, create a Zoom trace with the source traces of interest. The Zoom traces can be overlaid.

One additional tip: to quickly move a trace, drag its descriptor box to the desired grid, as shown in Figure 21.

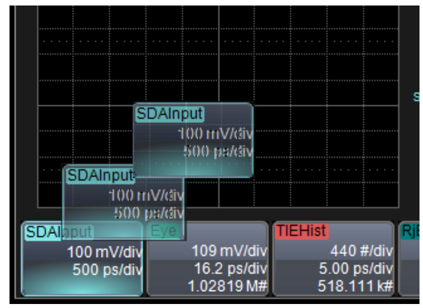


Figure 21: To quickly move a trace to a grid, simply drag-and-drop the descriptor box to the desired location.

Conclusions

SDAIII-CompleteLinQ provides a unique set of tools to understand and characterize crosstalk. LaneScape Comparison Mode and the Reference Lane allow users to easily compare results from two different scenarios, such as aggressor on-off analysis. Upon performing the analysis, users can see how crosstalk affects jitter and noise measurements, such as Tj/Rj/Dj and Tn/Rn/Dn, and then view tracks, histograms, spectra, eye diagrams and the “crosstalk eye” in order to obtain insight into the nature and extent of the crosstalk. The analysis performed in this application note can be performed on WavePro/SDA/DDA 7 Zi/Zi-A, WaveMaster/SDA/DDA 8 Zi/Zi-A, LabMaster 9 Zi-A and 10 Zi series oscilloscopes when equipped with the vertical noise analysis capabilities. The “Crosstalk”, “CrossLinQ and “CompleteLinQ” products that are part of the SDAIII-CompleteLinQ family include the vertical noise analysis tools.

Appendix – Noise Measurements Calculation Process

The noise measurements are determined via the following process:

1. Measuring noise utilizes pattern analysis to distinguish the signal from the noise. In the simple case of a strictly repeating pattern, such as PRBS7, which includes 127 bits, the oscilloscope can find the bit pattern in the waveform, and identify all occurrences of any particular bit. When the data is not a repeating pattern, the oscilloscope can look for repetitions of shorter runs to identify patterns. By averaging the waveforms for each corresponding bit in a pattern, (while taking into account small variations in the bit width due to PLL tracking), a noiseless version of the pattern can be constructed.
2. Subtracting the noiseless version of the pattern (iterated as necessary) from the original waveform returns a noise waveform without the data-dependent effects that can cause relatively large and deterministic variations in amplitude from unit interval to unit interval (e.g intersymbol interference). When retaining only the values of this waveform at a selected position in each unit interval (the “Sampling Phase”), a waveform that contains the noise seen by a receiver that samples or strobes each unit interval is created. This is the **RnBUnTrack** waveform, which contains random and bounded uncorrelated noise, and which has data dependent effects removed. This data can also be histogrammed to form the **RnBUnHist** histogram. RUnBUnTrack and RnBUnHist can be used to understand sources of noise that can cause bit errors, and can be enabled for display via the **Noise Track** and **Noise Histogram** dialogs. These results are also the source data for the calculation of the noise measurements that are enabled in the **Noise Measurements** dialog. The next steps in the measurement of these parameters follow closely the algorithm that is used to calculate horizontal jitter.
3. The selection for the model used to calculate the jitter results is used in the noise measurements. The **Dual-Dirac Spectral** methods use the FFT of the RnBUnTrack waveform, called **RnBUnSpect**. Peaks in this spectrum above a calculated noise floor are associated with periodic noise, and are removed and used to calculate a value for Pn (see below). The remaining spectrum is used to form a sigma value by integrating RnBUnSpect. (Square root of the sum of the magnitudes squared.) In the **Spectral Rj Direct** method, this sigma value becomes the value of Rn itself. In the **Spectral Rj+Dj CDF Fit** method, the sigma value is used to fit the tails of the RnBUn histogram.
4. The distribution of data dependent “noise” that was removed in the time domain by averaging to form the RnBUn trace is convolved with RnBUnHist to form an overall probability density function (PDF). This is done independently for both the high and low levels, resulting in two PDFs. Integrating these functions gives cumulative probability density functions, or CDFs for high and low levels. The inner halves of these distributions are taken and put together in order to form a CDF that provides information about the total noise that contributes to eye closure and bit errors.
5. In the Rj+Dj CDF Fit method, the CDF is then fit to the dual-Dirac equation Tn = alpha(BER) Rn + Dn, using 4 values of BER about the BER the user has selected in the GUI to return values for Rn and Dn. In the Spectral Rj Direct method, this fit is performed with the constraint that Rn = sigma.
6. When using the NQ-scale method, the tails of RnBUnHist are fitted to two Gaussian distributions that can have both different sigmas and different populations. The data dependent noise is convolved in as described above, and Tn, Rn and Dn is determined as described above for the Rj+Dj CDF Fit method.
7. Pn is determined by isolating just the peaks found in step 3 above, and taking the iFFt of the spectrum including only the peaks. The peak-to-peak amplitude resulting waveform is returned as periodic noise.
8. ISIn is determined by analyzing the distribution of voltages at the sampling phase, for the high and low levels separately.
9. Tn is used to calculate an estimate of the eye opening at BER. The measurement EyeHeight @ BER (EH(BER)) is the Eye Amplitude - Tn.